LARGE Antennas in Space:
Concepts, Options and Challenges

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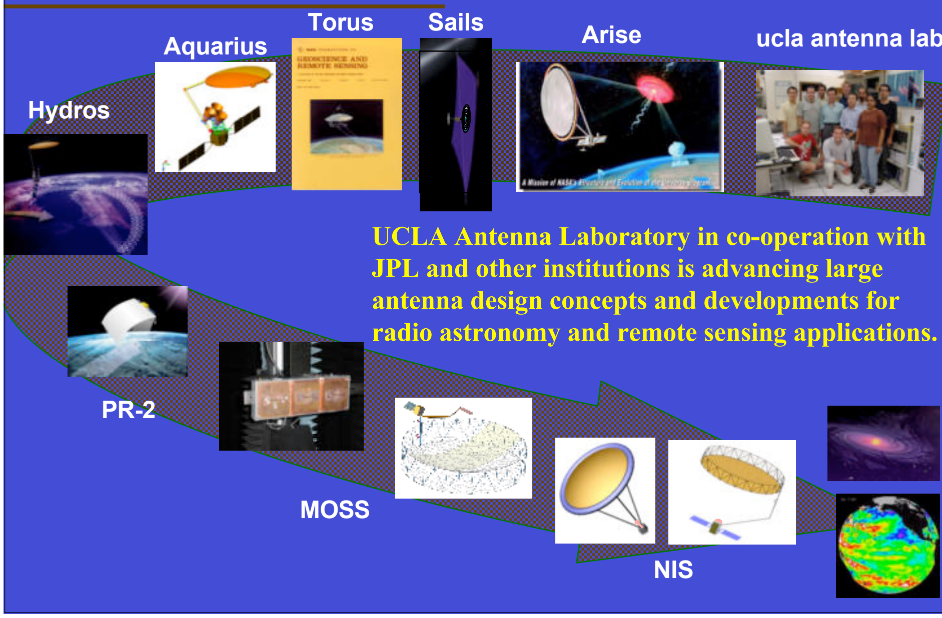
EE Department:2002-03
UCLA
Faculty: 47
Lecturers: 17
Admin. Staff: 48
Publications
Paper: 139
Conference: 264
Book/Chapter: 14
Patent Issued: 7
Many Awards
Research
Fund: $22.8 M
Supports:
Fellowships
RA-Ships
TA-Ships
Readers
Students
Undergrad Students: 752
Graduate Students: 444
Degrees Conferred:
B.S.: 172, M.S.: 111, Ph.D.: 29

Universities must be considered as vital players in creating new and visionary concepts for future missions.

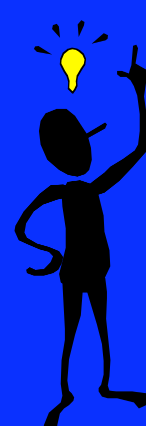


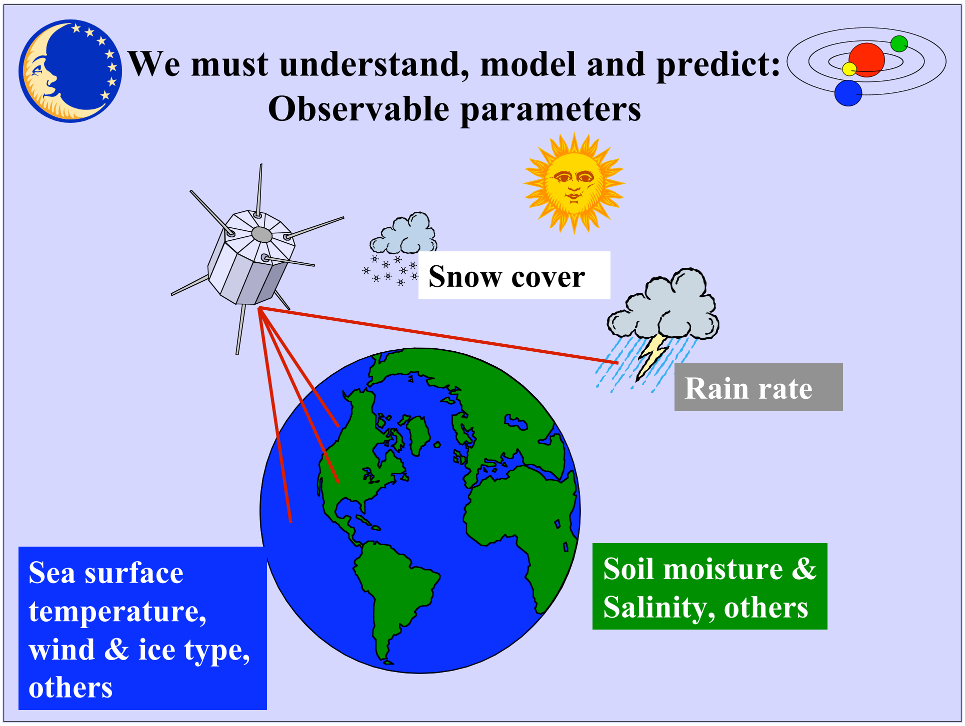
UCLA Antenna Laboratory in co-operation with JPL and other institutions is advancing large antenna design concepts and developments for radio astronomy and remote sensing applications.

One needs to dream big!

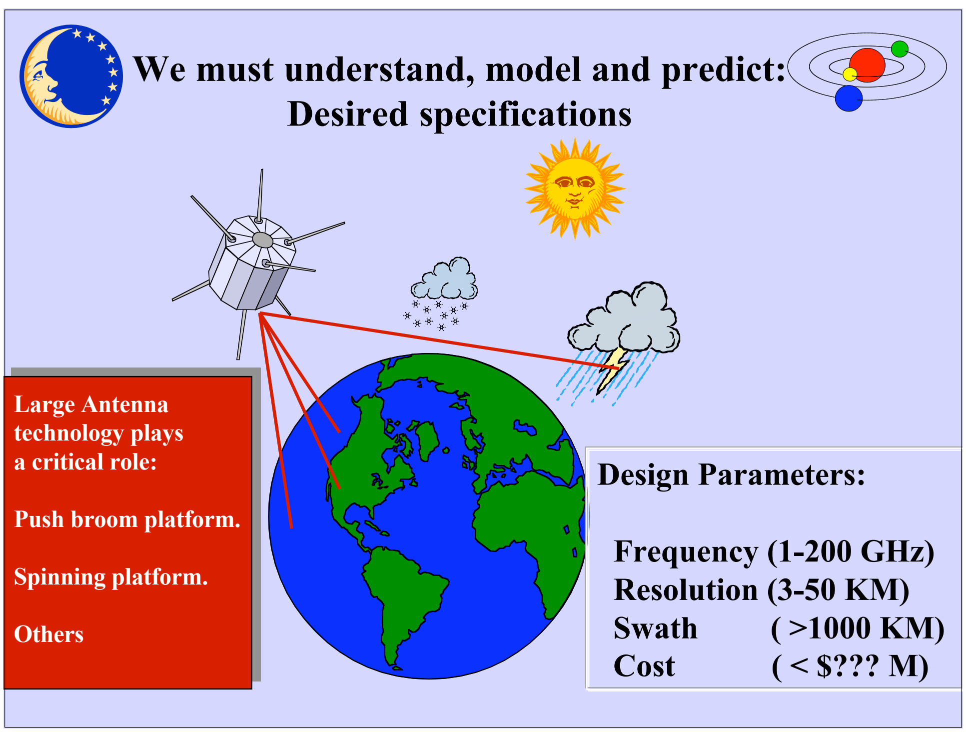
"It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow."

R. H. Goddard





We must understand, model and predict:
Observable parameters
Snow cover
Rain rate
Sea surface temperature, wind & ice type, others
Soil moisture & Salinity, others



We must understand, model and predict:
Desired specifications
Large Antenna technology plays a critical role:
Push broom platform.
Spinning platform.
Others
Design Parameters:
Frequency (1-200 GHz)
Resolution (3-50 KM)
Swath (>1000 KM)
Cost (< $??? M)

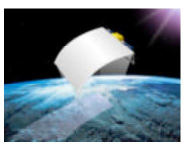
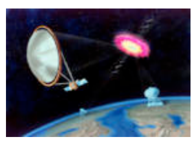
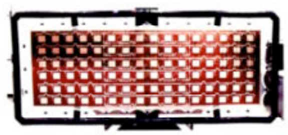
How does an antenna radiate?

Fact from physics: Accelerated charges radiate.

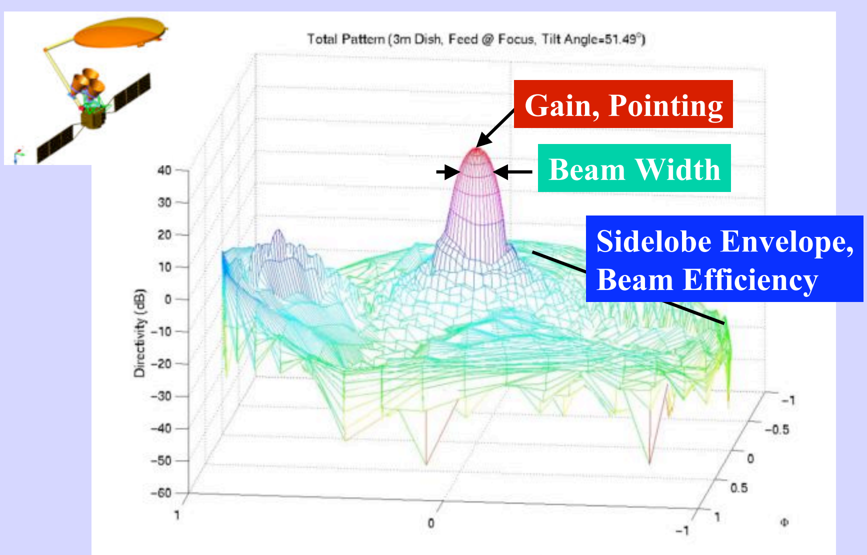
I = q v	**dI/dt = q dv/dt**
current = charge x velocity	time varying current = accelerated charge

Observation: Time varying currents produce electromagnetic radiation governed by Maxwell's equations.

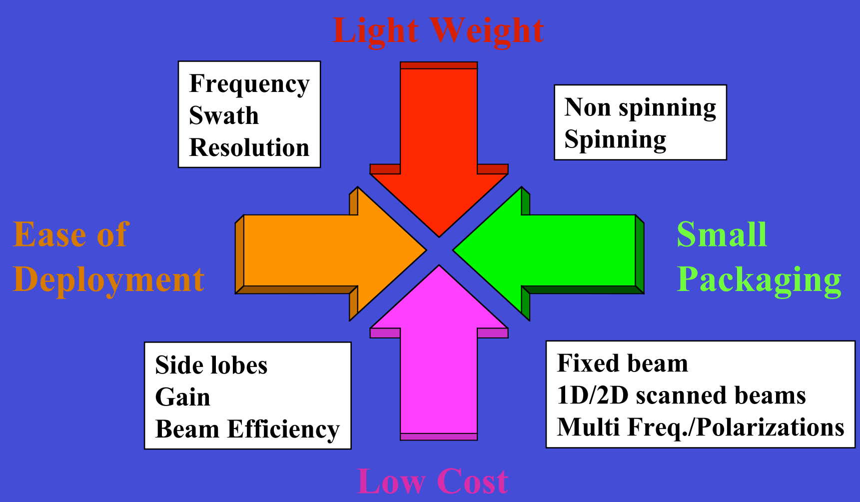
Antennas: Electromagnetic devices controlling the flow of the time varying currents; thus, producing EM radiation with desired characteristics.


Antenna pattern is the manifest of the spatial Fourier transform of its current distribution

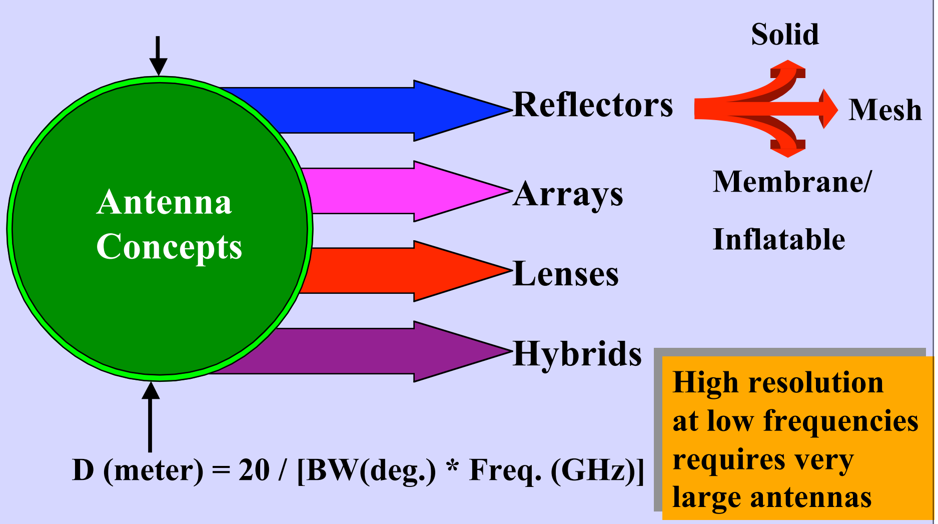


System Parameters for Large Space Antennas



The challenge is how to achieve required performance!

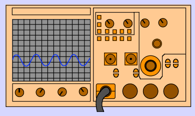
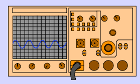
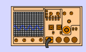
Antenna Classifications



D (meter) = 20 / [BW(deg.) * Freq. (GHz)]

Example: D (meter) = 20 / [1.1(deg.) * 1.4 (GHz)] = 13.0 meters

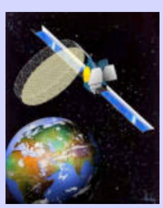
Microwave Components are becoming smaller! Antenna aperture stays LARGE for desired resolution!

	1970's	1980's	1990's
Microwave component size			
Antenna aperture size			

How to obtain LARGE apertures?

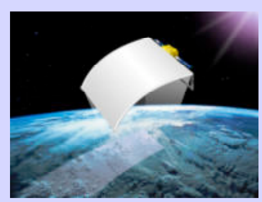
Filled apertures:

2-D curved



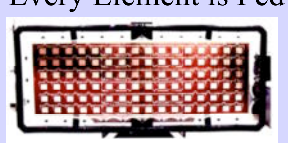
2-D curved

1-D Curved

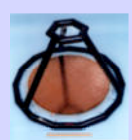


Discrete dense apertures:

Every Element is Fed

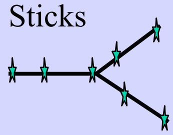


Space Fed



Discrete sparse apertures:

Sticks



Formatio
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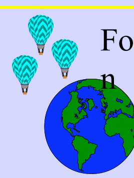
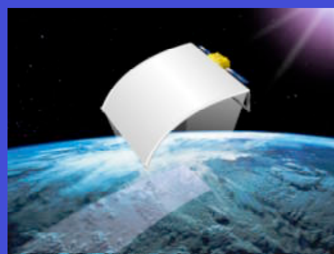
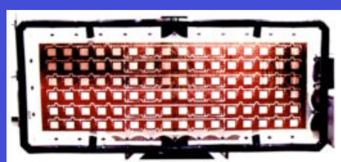
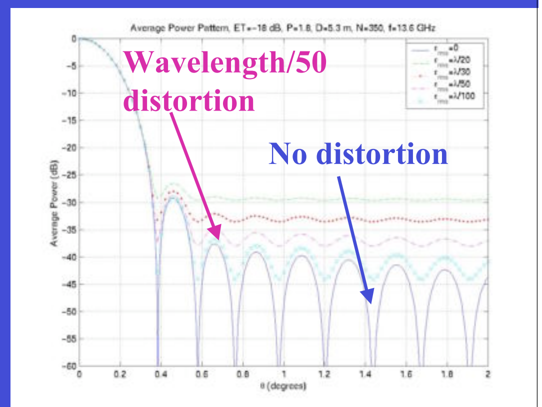


Effects of surface RMS on antenna pattern







Depending on the desired sidelobe envelope, surface RMS better than wavelength/50 (for reflector antennas) and wavelength/25 (for array antennas) may be required.

Reflector Design Options

Symmetric Parabolic

Offset Parabolic

Spherical

Cylindrical

Torus

Cassegrain

Gregorian

Others

Feed Design Options

Conical Horns

Corrugated Horns

Patch arrays

Multi Polarizations

Multi Frequencies

Others

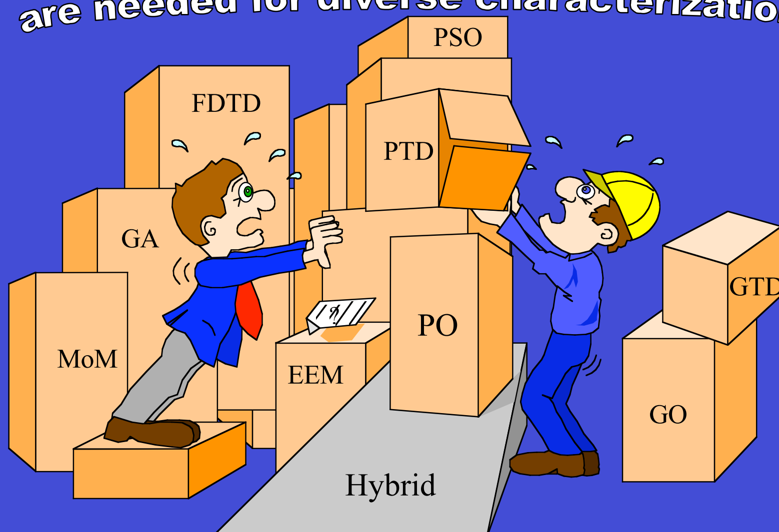
Satellite Communication Industry is relying on large deployable mesh reflector antennas

12 m antenna
2000-2004

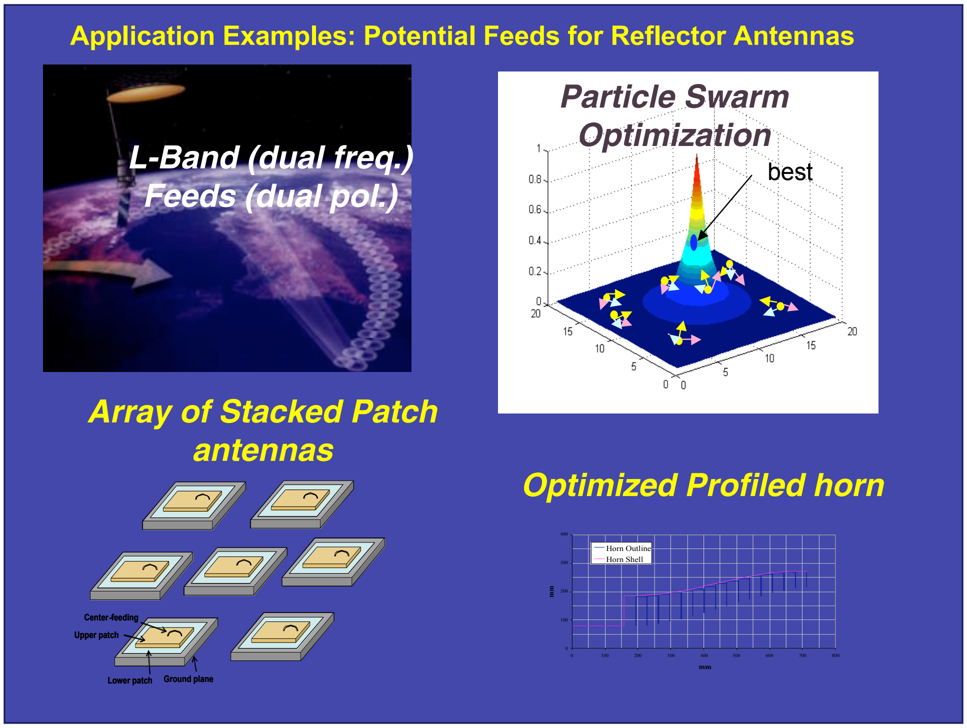
A. G. Roederer and Y. Rahmat-Samii, "Unfurable Satellite Antennas: A Review," Annales des Telecommunications, vol. 44, no. 9-10, pp. 475-488, November, 1989.

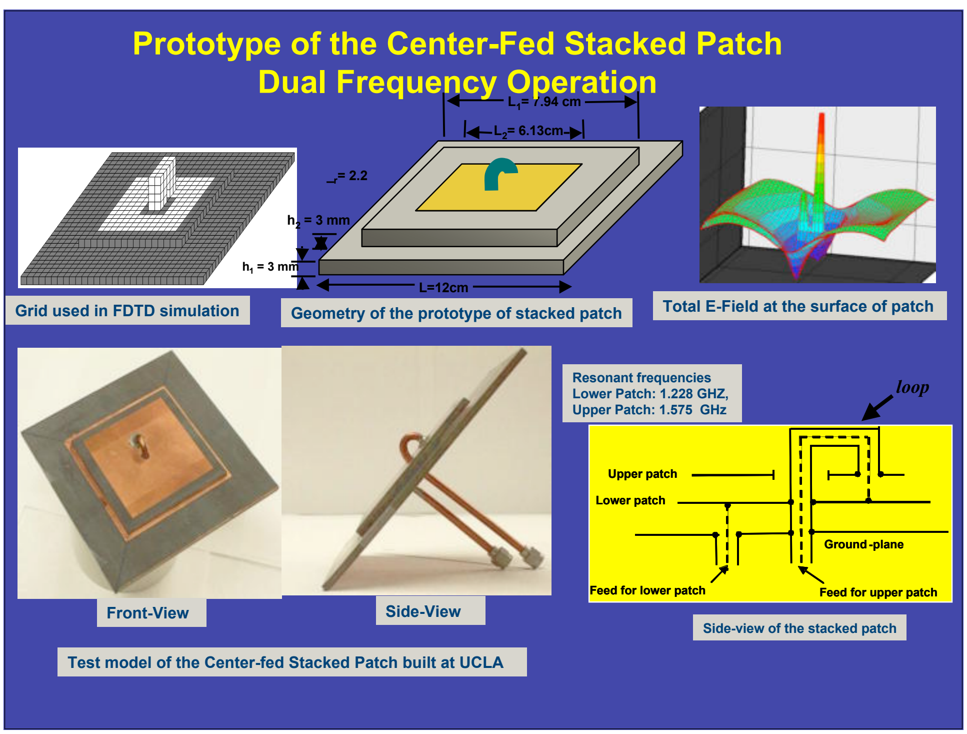
Electromagnetic Computations

Various computational techniques are needed for diverse characterizations



Advanced EM computation/optimization tools are critical .

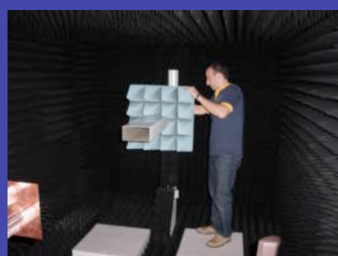

Application Examples: Potential Feeds for Reflector Antennas
L-Band (dual freq.)
Feeds (dual pol.)
Particle Swarm
Optimization
best
Array of Stacked Patch
antennas
Center-feeding
Upper patch
Lower patch
Ground plane
Optimized Profiled horn
Horn Outline
Horn Shell


Prototype of the Center-Fed Stacked Patch
Dual Frequency Operation
L_1= 7.94 cm
L_2= 6.13cm
ϵ_r= 2.2
h_2 = 3 mm
h_1 = 3 mm
L=12cm
Grid used in FDTD simulation
Geometry of the prototype of stacked patch
Total E-Field at the surface of patch
Resonant frequencies
Lower Patch: 1.228 GHZ,
Upper Patch: 1.575 GHz
loop
Upper patch
Lower patch
Ground-plane
Feed for lower patch
Feed for upper patch
Front-View
Side-View
Side-view of the stacked patch
Test model of the Center-fed Stacked Patch built at UCLA

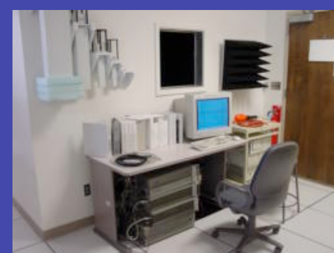
Stacked Patch in the Spherical Near Field Measurement Chamber at UCLA

Stacked Patch with Center-Feeding

Front-view of Stacked Patch with fixture



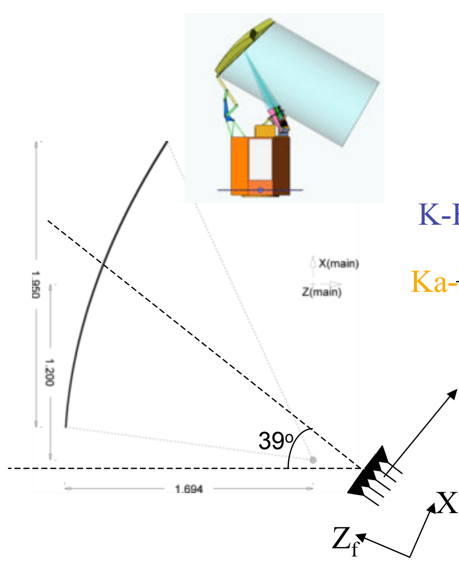
L-Band Probe used for Measurement



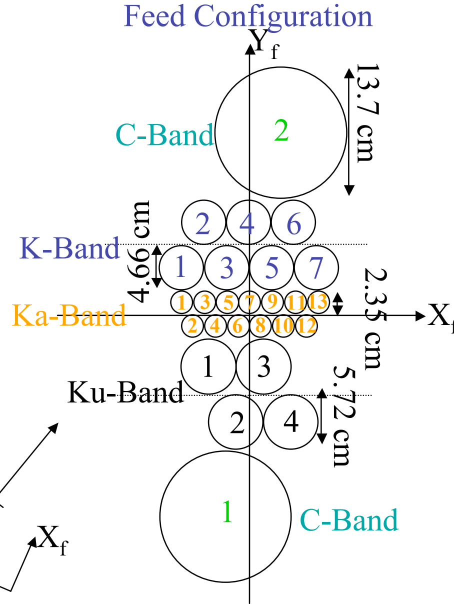
Near-Field Measurement Chamber

An Offset Parabolic Reflector Antenna & its Feed Farm

Antenna Geometry



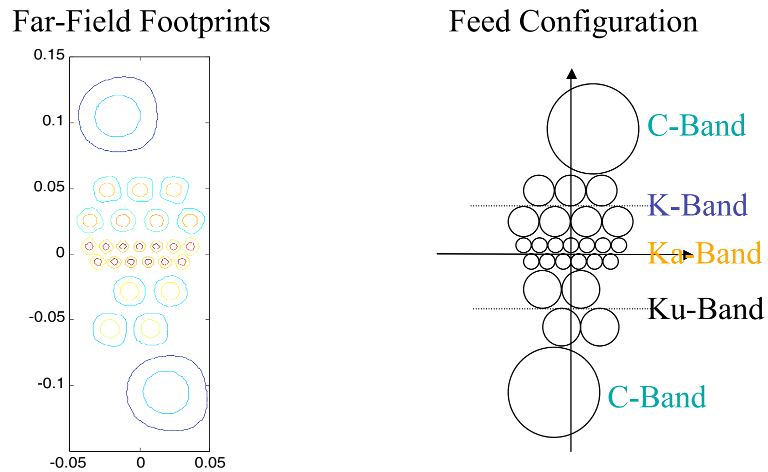
Feed Configuration



Note: In this figure Y is the flight direction.

An Offset Parabolic Reflector:

The overall beam footprints



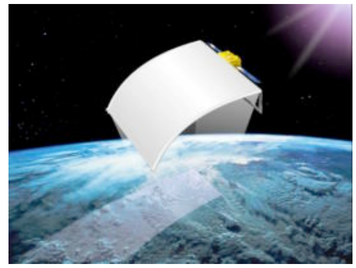
Inner Contour= -3 dB

2nd Contour= -10 dB

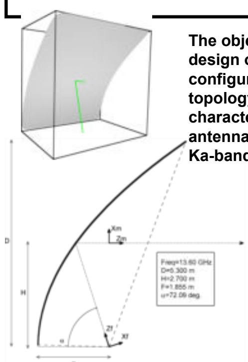
5.3 m by 5.3 m Offset Cylindrical Parabolic Reflector Antenna with Linear Array Feed for 1-D Beam Steering at Ku and Ka Bands

Precipitation Radar Antenna (PR-2) : Offset Parabolic Cylindrical Reflector Antenna

Novel Features:
- Incorporates dual-frequency with matched beams.
- Improves horizontal resolution to achieve wide-angle scanning of 30 deg.
- Avoids feed blockage.
- Better cross-polarization isolation as compared to a parabolic reflector.
- Light weight.

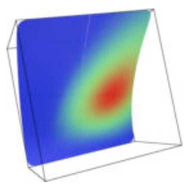


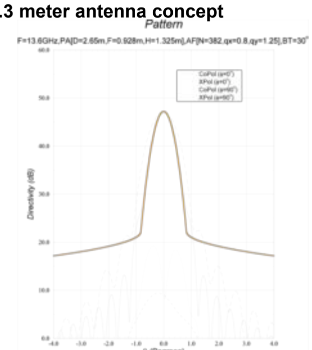
5.3 meter antenna concept



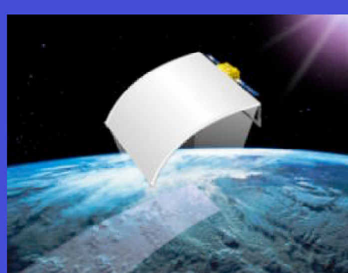
The objectives are: (i) the optimal design of the antenna configuration, (ii) feed array topology selection and (iii) characterization of the overall antenna performance at Ku and Ka-band frequencies.

Current





14/35-GHz Doppler Precipitation Radar



Current Status

IIP PR-2 and APRA Tasks:
- 2.7mx2.7m Ku- and Ka-band
- 0 and 30˚ beam pointing
- Prototype model complete in 9/04

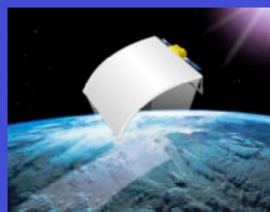
APRA Prototype: reflector & Ku-band feed

Tasks Needed for 6mx6m cross-track scanning (±35˚) reflector
1. Space rigidization reflector structure
2. Longevity of membrane material for space
3. Ka-band T/R modules each at 0.75-W power level
4. Ka-band phase shifters with low insertion loss
5. Ka-band linear feed technologies (dual-polarization with 30-dB cross-pol isolation)
6. Verification method to compensate for gravitational loading (artificial) effect during ground testing
7. Metrology to detect the reflector surface distortion
8. Compensation of distorted reflector surface

Current TRL: 3
IIP Exit TRL: 5

Future Effort for reaching TRL=7
- Two years
- $3M

14/35/94-GHz Doppler Precipitation/Cloud Radar



Tasks Needed for 6mx6m cross-track scanning (±35˚) reflector

1. Space rigidization reflector structure
2. Longevity of membrane material for space
3. Ka/W-band T/R modules each at 0.75-W power level
4. Ka/W-band phase shifters with low insertion loss
5. Ka/W-band linear feed technologies (dual-polarization with 30-dB cross-pol isolation)
6. Verification method to compensate for gravitational loading (artificial) effect during ground testing
7. Metrology to detect the reflector surface distortion
8. Compensation of distorted reflector surface

Current Status

IIP PR-2 and APRA Tasks:

- 2.7mx2.7m, 0/30˚ pointing Ku- and Ka-band
- Prototype model complete in 9/04

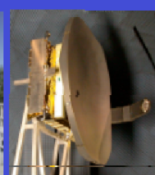
ESSP CloudSat radar:

- 2mx2m, nadir pointing W-band
- Flight model completed in 3/03

Current TRL: 1
IIP Exit TRL: 3

APRA reflector

APRA Ku-band feed



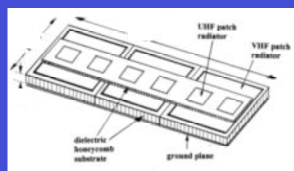
CloudSat antenna

Future Effort for reaching TRL=7

- Five years
- $8M

Array-Fed 30 m Parabolic Reflector Antenna Creating Matched Beams at VHF and P Bands

Multifrequency Dual-pol Feeds for Custom Aperture Formation on Large Reflectors



Current Status

MOSS: Dual-frequency double-stack planar feed will be at TRL-5 by end of 2004:

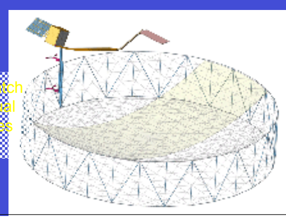
--- 1:10 scale built/tested, currently being integrated with reflector for overall system testing

--- full scale feed under construction

--- achieves effective dual rectangular apertures on circular reflector

Tasks Needed for Multifrequency Dual-polarization Low-profile Feeds:

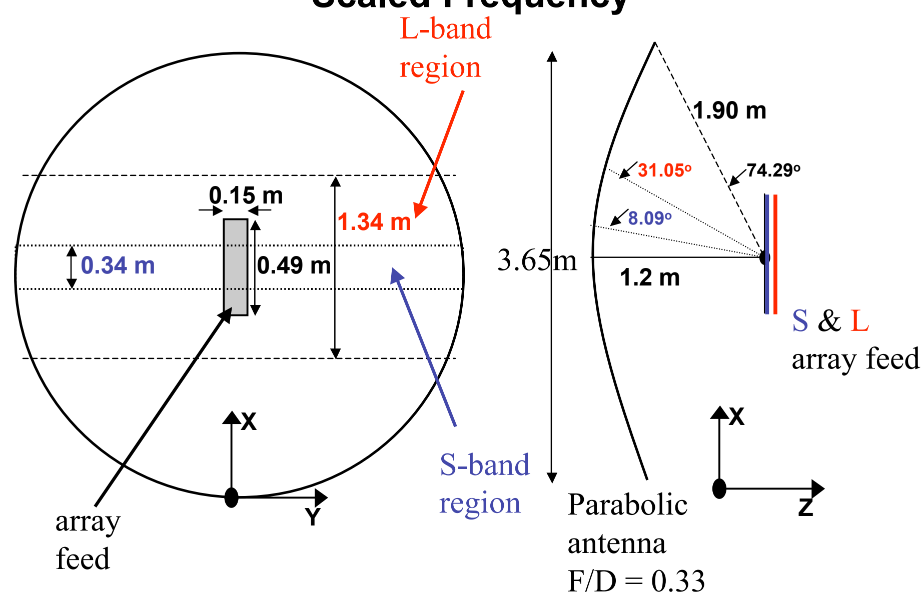
1. Relevant (launch environment) testing for MOSS' dual-frequency feed
2. Concurrent radar and radiometer system-level designs at multiple relevant frequencies (start with three)
3. Multiple stack planar feed design, including feed placement and movements
4. numerical simulation to demonstrate performance
5. Design of multifrequency power-dividing networks
6. Highest priority frequencies are 0.13-1.3 GHz
7. Fabrication and ground testing at 1:10 scale frequencies, then at full-scale
8. Testing of full scale engineering model at relevant launch environment



UHF/VHF stacked patch feed synthesizing dual rectangular apertures for MOSS

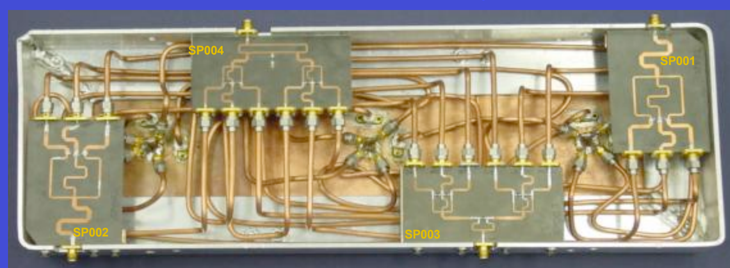
Current TRL (2 freqs): 5
Current TRL (3 or more freqs): 2
Exit TRL: 6

3.65-m Reflector Antenna Geometry: Scaled Frequency



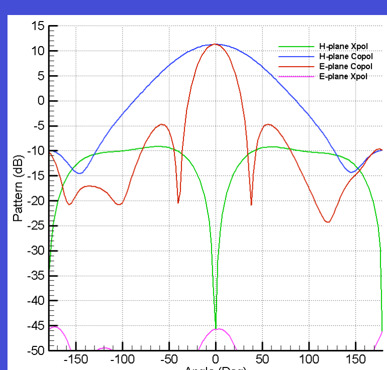
Dual-Frequency Dual-Polarized Stacked Patch Microstrip Array

Front-View of the Array

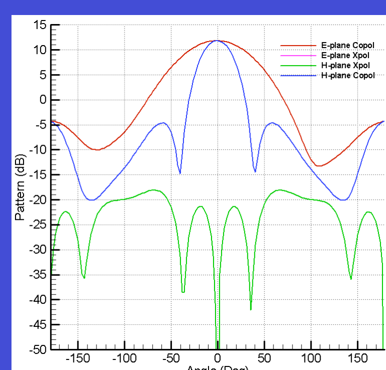


Back -View of the Array

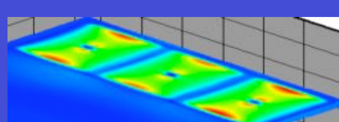
Simulation Results for the Array (Lower Patch)



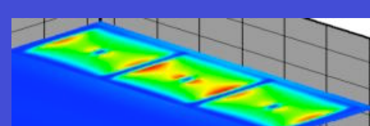
Radiation Pattern (Array Polarized)



Radiation Pattern (Cross-Array Polarized)

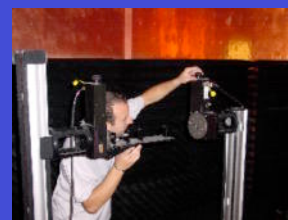


Simulated Current Distribution on Array (at last time-step)
(Array Polarized)

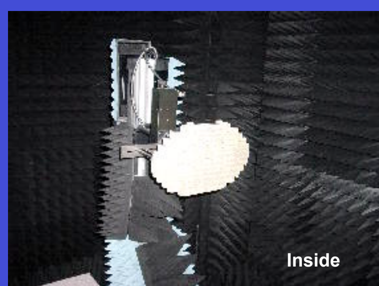


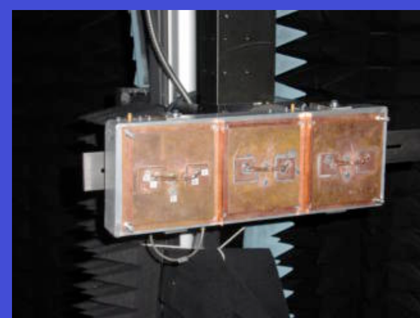
Simulated Current Distribution on Array (at last time-step)
(Cross-Array Polarized)

UCLA Spherical Near Field Measurement Chamber

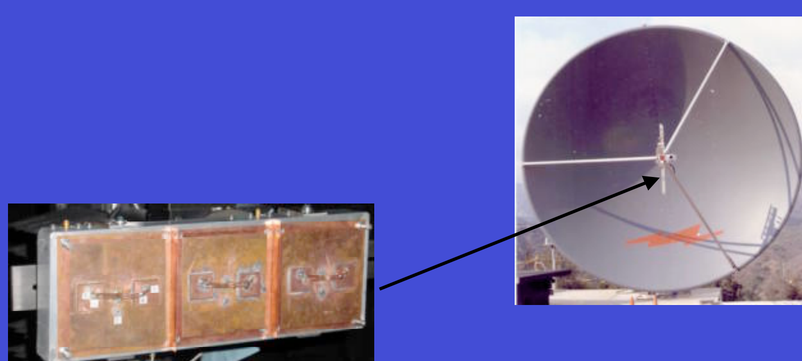


Array Antenna in the Chamber



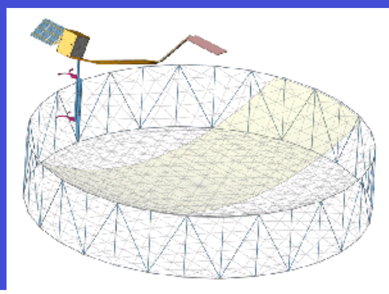


Parabolic Reflector to be Fed by the Array: Proof of Concept



3.65-m parabolic
reflector antenna
with F/D = 0.33

30m AM2 Mesh Reflector, 0.13-1.3 GHz



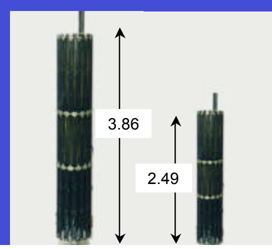
AM2 30-m reflector+feed and S/C point design for MOSS

Tasks Needed for 12-50m AM2 reflector

(2) scaled engineering model (12m) of AM-2 reflector technology
(3) Component level ground verification of all "new" full-scale components and subsystems in their relevant environment(s)
(4) Testing a scaled AM2 antenna system (such as existing 12-meter engineering model) in the relevant launch environment
(5) Establish the remainder of TRL 6 status by similarity to heritage
(6) Feed technologies (for example, planar and multi-frequency feeds - see associated slide)

Current Status

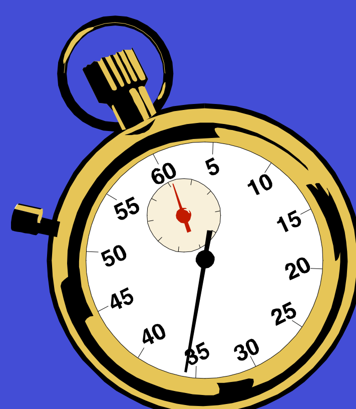
1. Thuraya: 12m diameter at TRL 9, with Astro-Mesh-1 (AM1) technology
2. Northrop-Grumman (Astro) will take the new Astro-Mesh-2 (AM2) technology to TRL 5 in near future. AM2 has considerably lower package volume compared to AM1, and is applicable to up to 50-m class reflectors. TRL 6 is achievable in 2006-2007 timeframe.



Package height in meters: AM1 (left) and AM2 (right) for a 12m reflector

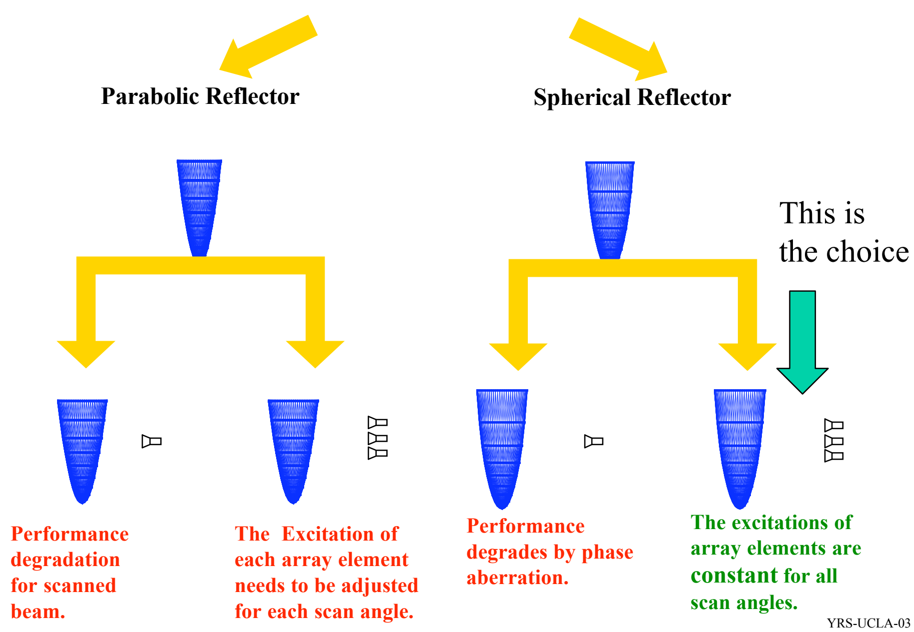
Current TRL: 5
Exit TRL: 6

How am I doing with the time?



Array Compensated 35 m Spherical Reflector Antenna with Spiral Feed Motion for Producing Large Scan at Ka Band

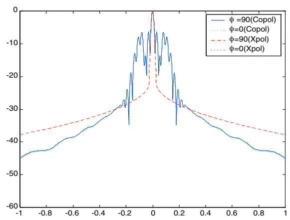
Potential Design Concepts



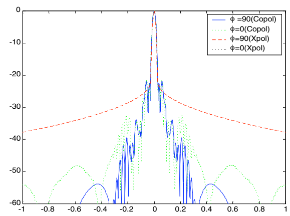
YRS-UCLA-03

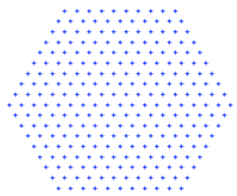
Array Compensated Spherical Reflector Antenna
Freq = 35.6 GHz

Uncompensated



Compensated





	Un compensated	Compensated
Directivity (dB)	67.62	77.48
HPBW (deg.)	0.018	0.022

Noticeable improvement is observed.

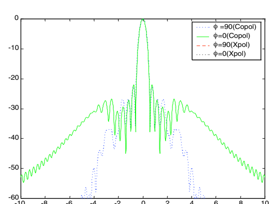
YRS-UCLA-03

1.5 meter Spherical Reflector Antenna
Scanning Performance

F/D= 0.4, F/ Dill. = 0.45
Hexagonal Array

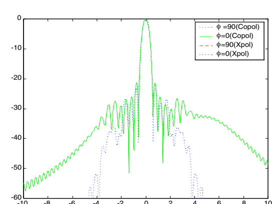
No Scan Case

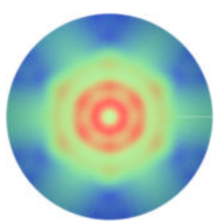
Directivity =51.47 dB



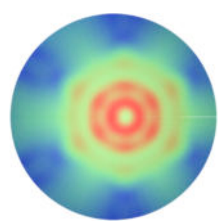
4^o Scan Case

Directivity =51.42 dB



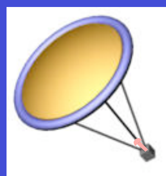


Surface Current on the reflector

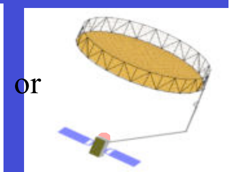


YRS-UCLA-03

35-GHz Geostationary Doppler Hurricane Radar



or



Tasks Needed for 35m spiral-scan reflector

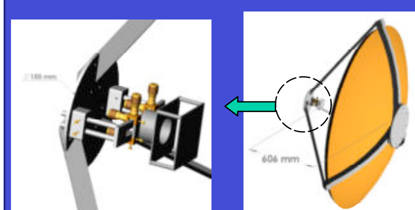
1 Light weight, rigid, deployable spherical reflector
2. Longevity of membrane/mesh material for space
3. Innovative low-loss power dividing network Ka-band low-loss planar array feed technologies
4. Innovative electro-mechanism for spiral scanning for twin array feeds
5. Ground testing and verification method (hybrid of measurements and simulation)
6. Verification method to compensate for gravitational loading (artificial) effect during ground testing
7. Metrology to detect the reflector surface distortion
8. Adaptive compensation of distorted reflector surface

Current Status

IIP Nexrad-In-Space (NIS) Tasks:

- 1.5m (dia.) Ka-band variable pointing prototype
- Electro-mechanical scanner demonstration model
- Models to be completed in 10/05

Current TRL: 2
IIP Exit TRL: 4



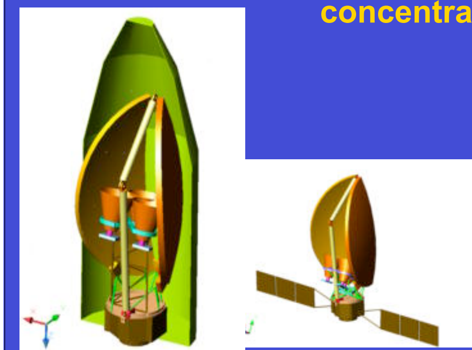
NIS Prototype Antenna Design

Future Effort for reaching TRL=7

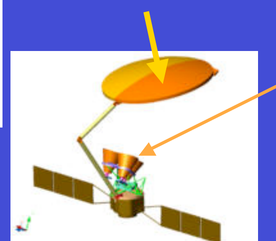
- Five years (from IIP Exit in 10/05)
- $6M (exclude 35-m reflector)
  - Leverage off on-going reflector development

Spinning (and non spinning) Reflector Antenna Designs at L Bands

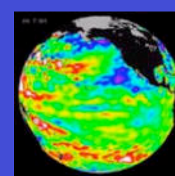
Aquarius: Global maps of ocean-salt concentration and Soil Moisture



3 m foldable reflector antenna for earth observation

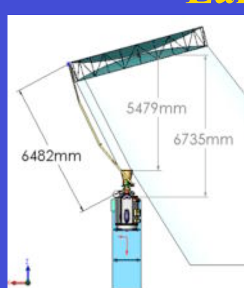


GA Optimized horns



E. G. Njoku, W. J. Wilson, S. H. Yueh and **Y. Rahmat-Samii**, "A Large-Antenna Microwave Radiometer-Scatterometer Concept for Ocean Salinity and Soil Moisture Sensing," IEEE Transactions on Geoscience and Remote Sensing, Vol. 38, No. 6, pp. 2645-2655, Nov., 2000.

Large Spinning Reflector



Tasks Needed for 6-30m rotating reflector

1. Light weight, rigid, deployable reflector (highest frequency Ku-band)
2. Finite element analysis tools
3. Ground testing and verification method
4. Compensation of distorted reflector surface
5. Metrology to detect the reflector surface distortion

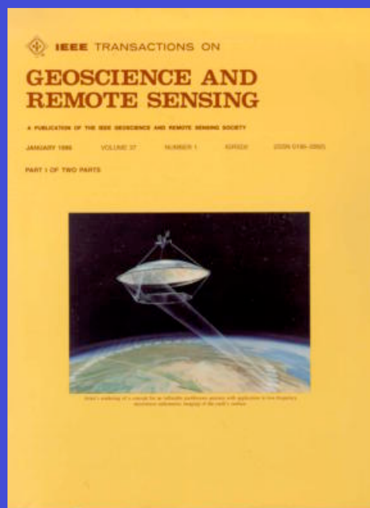
Current Status

1. HYDROS: 6m (diameter) rotating antenna at L-band)
2. HYDROS will improve TRL 4 to TRL 6

Current TRL: 3
Exit TRL: 6

Example: NGST Astro deployable mesh antenna

Torus-class Antennas can provide viable solutions for overcoming spinning large reflector antennas



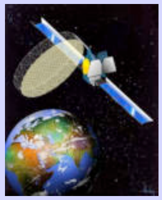
There are many varied configurations for torus class reflector antennas which require further studies.

Large Membrane Array and Reflectarray Antennas at L, X and Ka Bands

How to obtain LARGE apertures?

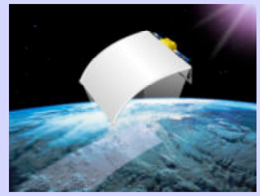
Filled apertures:

2-D curved



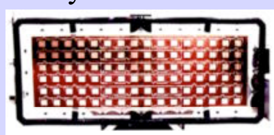
2-D curved

1-D Curved



Discrete dense apertures:

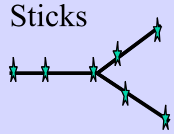
Every Element is Fed



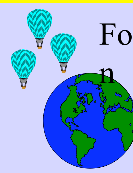
Space Fed

Discrete sparse apertures:

Sticks

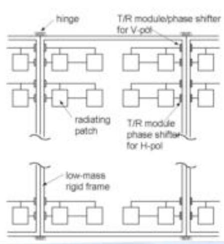


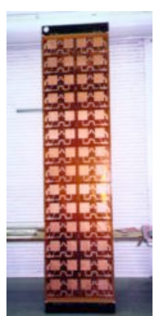
Formatio
n

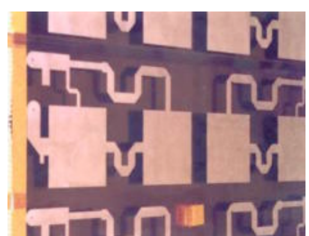


Microstrip Array:Discrete Dense Aperture Element Fed

Foldable Framed Thin-Membrane L-Band Array







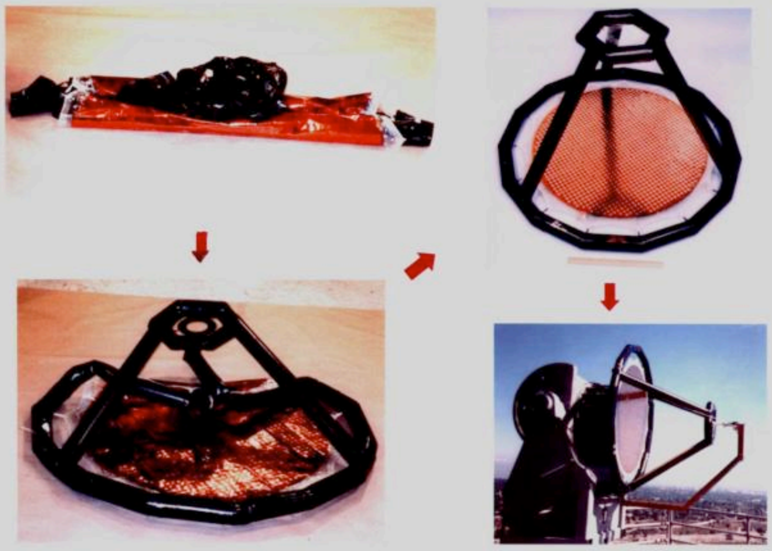
Close-up view
2-layer thin-membrane

Each panel

Mass density = 1.8 kg/m²

Full-size 5m x 3m 7-panel array

JPL 1 m X-Band Inflatable Microstrip Reflectarray



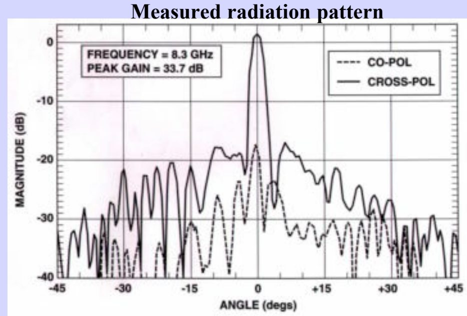
Reflectarray: Discrete dense aperture with space-fed elements

1m X-band reflectarray

By JPL / ILC Dover

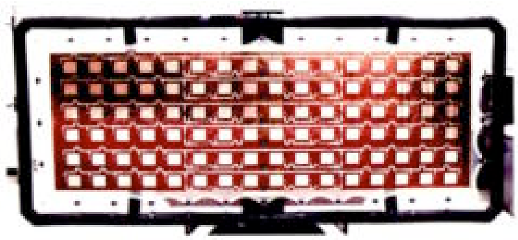
- Circularly polarized
- Approx. 1000 elements
- 2-layer membranes
- Patch/ground plane separation is 1.3mm
- Kevlar tube / Kapton membrane
- Radiation efficiency = 37%
- Achieved surface flatness<0.8mm

Measured radiation pattern



SAR Arrays: Discrete Dense Aperture Element Fed

Two L-band inflatable SAR arrays were developed



ILC Dover design

L'Garde design

- Antenna concepts and RF designs were done by JPL, inflatable structures were done by ILC Dover and L'Garde
- Both models use inflatable tubes to support a multilayer membrane aperture
- Material: Kevlar tube/Kapton membrane
- Efficiency achieved: ILC Dover 52% L'Garde 75%
- Achieved surface flatness < 0.8mm

Concluding Remarks

Observations

Existing programs have advanced our understanding of potential applications of large deployable antennas.

Follow up research and development activities are needed to make them technologically ready for spaceborne utilization.

Technological readiness for Reflector Antennas:

Membrane/Inflatable Reflector Antennas

No existing commercial heritage for offset antennas.

Utilization on a spinning platform requires evaluation.

Surface accuracy and profile needs characterization.

Utilization of an adaptive surface correcting system will enhance performance at high frequencies.

Some of the concepts could be evolved to 25-m aperture dimensions.

Both ground and in-flight characterizations/diagnostics are necessary.

Technological readiness for Reflector Antennas:
Mesh Deployable Reflector Antennas

Existing commercial heritage for up to 12.5m offset antennas.

Utilization on a spinning platform requires evaluation.

Needs to be evaluated for frequencies beyond 20 GHz.

Surface accuracy and profile needs characterization and adaptive correction may be necessary.

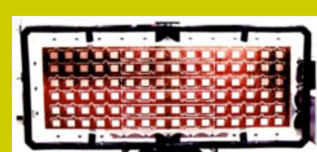
Some of the concepts could be evolved to 25-m aperture dimensions.

In-flight demonstration will create confidence.

The Development of Inflatable Arrays

Future challenges in the RF area:

- **Bandwidth improvement > 15%**
- **Dual-band shared aperture**



- **Membrane mounted T/R module/phase shifter with dc control circuitry**
- **RF power distribution on large aperture (> 10m)**
- **Noise temperature & beam efficiency characterization**

Thank you